



ABSOLUTE GRAVITY MEASUREMENTS IN YELLOWSTONE IN SEPTEMBER 2009

Intermediary Report - August 2010

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Foreword

This report contains the results of absolute gravity measurements carried out in Yellowstone in September 2009. The team includes Prof. Olivier Francis and Prof. Tonie van Dam from the University of Luxembourg in collaboration with Prof. John Wahr from the University of Colorado in Boulder and Dr. David Schmerge, Tim Wilkins and Mark Eckl from the National Oceanic Atmospheric Administration (NOOA).

The absolute gravimeter FG5#111 from the National Science Foundation (USA) has been used. The vertical gravity gradient as well as local gravity tied were measured with the spring gravimeter Scintrex from the University of Luxembourg.

The objective of this first absolute gravity campaign was to establish two new AG stations in Yellowstone. One was installed in Lake and the other one at Old Faithful (see Figure 1). The National Park guards have been extremely helpful in finding sites meeting the field specifications: safety, as far as possible from human activities and close enough to electric power.

The fieldwork presented in this report was funded by the European Center for Geodynamics and Seismology, Luxembourg.

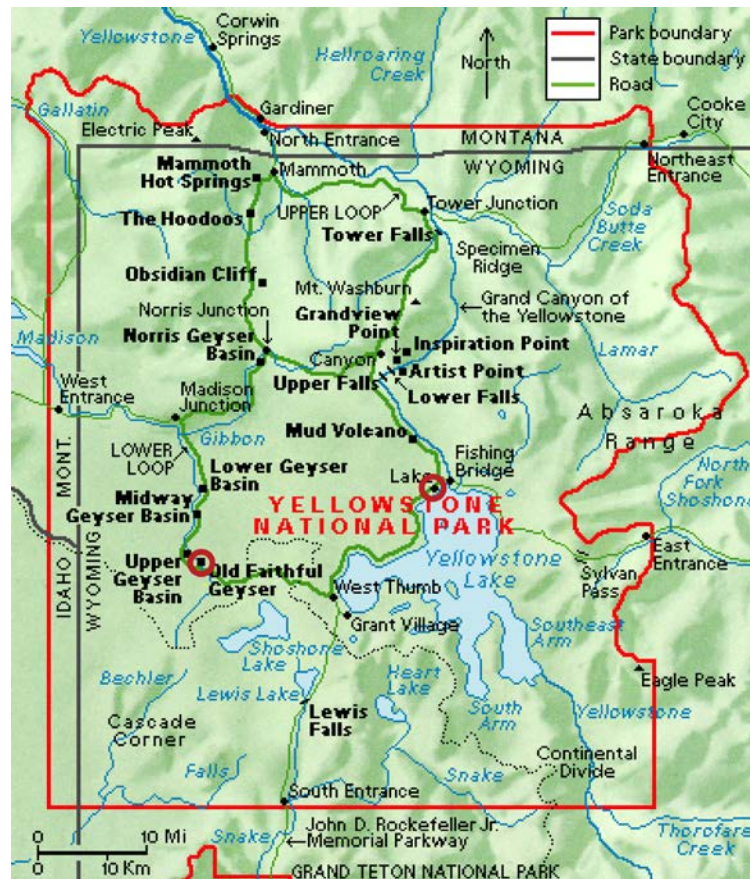


Figure 1. Map of the Yellowstone National Park

Absolute Gravity sites

The absolute gravity observations were performed outdoor in a tent (Figures 2). At Lake, the absolute gravity site is located in a service area. The site itself is located far enough away from the maintenance buildings, dormitories and camping ground to not be disturbed by car

traffic. The station is located on the tarmac on a parking lot of an official building. Electrical power is taken from the building itself.

At Old Faithful, the absolute gravity site is inside a disused water facility area. It has the advantage to be off the main road and protected by a fence. Electrical power is also available on site.

Old Faithful



Lake



Figures 2. Pictures of the absolute gravity sites at Old Faithful and at Lake.

Data processing

Raw data from the absolute gravimeters consist of vectors of time and position of the falling object during the drops. To obtain the gravity value, a linear equation representing the equation of motion is fit to the raw data including the gravity gradient which has been measured with relative meters.

The data processing follows the protocol adopted during absolute gravimeters comparisons at the BIPM in Sèvres (Francis and van Dam, 2003). Geophysical corrections are applied to the raw gravity data: Earth tides using observed tidal parameters, atmospheric pressure effect using a constant admittance, and the polar motion effect using pole positions from IERS.

The g-soft version 7.0 software from Microg-LaCoste Inc. was used for the processing. All the text outputs as well as some figures are compiled in the annexes of this report for future reference.

Vertical Gravity Gradient

The vertical gravity gradient was measured with the relative spring gravimeter Scintrex CG5 from the University of Luxembourg at the absolute gravity stations. This gradient is needed to linearize the equation of motion but also to transfer the measured absolute gravity value from the reference height around 1.3 m to the floor. The values of the linear vertical gravity gradient are given in Table 1.

Table 1. Vertical gravity gradient measured at the absolute gravity sites

Station	Vertical Gravity gradient /microgal/cm	Standard Deviation /microgal/cm
LAKE	-3.097	0.004
OLD FAITHFUL	-2.858	0.004

Results of the absolute gravity measurements

The FG5#111 observations started the Friday 29th of August until Saturday the 30th of August in Lake Village. A total of 31 sets of 100 drops (i.e. 3100 drops) were collected. The FG5 was then moved to Old Faithful where observations were carried out the 30th and 31st of August. A total of 50 sets of 100 drops (5000 drops) were collected.

The final processed gravity values are displayed in Table 2. All

Table 2. Final results of the absolute gravity measurements in the Yellowstone National Park.

Site	Gravity value @ 1.3m /microgal	Standard Deviation /microgal
LAKE	981 919 306.11	1.83
OLD FAITHFUL	981 919 663.87	2.49

Reference

Francis O., van Dam T.M., Processing of the Absolute data of the ICAG01, Cahiers du Centre Européen de Géodynamique et de Séismologie, vol.22, 45-48, 2003.

Financial Report

A detailed list of the different expenses for the 2009 gravity campaign in Yellowstone is given in table 3. Olivier Francis had to prepare and collect the absolute gravimeter in Boulder (Colorado) before the campaign. At the end of the campaign before returning the absolute gravimeter, measurements at Table Mountain Geophysical Observatory in Boulder were taken to verify the instrument.

Table 3. Absolute gravity campaign in Yellowstone (25/08/2009 to 04/09/2009)

Items	Details	Total
Per diem Tonie van Dam	190€ * 7 days	1 330,00 €
Flight ticket		943,75 €
Per diem Olivier Francis	190€* 10 days	1 900,00 €
Flight ticket		865,15 €
Rental car		770,00 €
Gas		111,41 €
Equipment shipping		1080.00 €
TOTAL		7000.31 €

ANNEXES

STATION: LAKE VILLAGE - YELLOWSTONE			
City:	Lake Village	Country:	USA
Location:	Service area	Particularity:	
Situation:		Remarks:	
Date:	28-29 August 2009		
Code number:			
Latitude:	44.56260 degrees		
Longitude:	-101.39630 degrees		
Elevation:	2398 m		
Gradient:	-3.097 µgal/cm		
Reference height: 0. 1440 m + 1.1633 m = 1.3073 m			
Meter:	FG5		
S/N:	111		
Tidal corrections using observed tidal parameters			
Polar motion correction			Air pressure correction
X-coordinate	0.2676	arc seconds	Nominal air pressure: 756.45 mbar
Y-coordinate	0.4236	arc seconds	Barometric admittance factor: 0.3 µgal/mbar
Gravity			
Set gravity mean:	979 864 511.58	Microgal	
Set std. dev.:	1.22	microgal	
Number of processed sets:	18		
Number of drops per set:	100		
Drop interval:	10 seconds		
Set interval:	30 minutes		
Nominal/datum height:	1.30 m		
Author: O. Francis	University of Luxembourg		
Date: October 30, 2009			

Project file

Micro-g Solutions g Processing Report
File Created: 07/13/10, 14:07:43

Project Name: LA20090828
g Acquisition Version: 8.090111
g Processing Version: 7.070307

Company/Institution:
Operator: Olivier Francis and David Schmerge

Station Data

Name: Lake Village
Site Code: Yellowstone
Lat: 44.56260 Long: -101.39630 Elev: 2398.00 m
Setup Height: 14.40 cm
Transfer Height: 130.00 cm
Actual Height: 130.73 cm
Gradient: -3.097 $\mu\text{Gal}/\text{cm}$
Nominal Air Pressure: 756.45 mBar
Barometric Admittance Factor: 0.30
Polar Motion Coord: 0.2676 " 0.4236 "
Earth Tide (ETGTAB) Selected
Potential Filename: C:\Program Files\Micro-g Solutions Inc\gWavefiles\ETCPOT.dat
Delta Factor Filename: G:\ABSOLU\DATA\INI\OceanLoad-Lake Village.dff
Delta Factors

Start	Stop	Amplitude	Phase	Term
0.000000	0.002427	1.000000	0.0000	DC
0.002428	0.249951	1.160000	0.0000	Long
0.721500	0.906315	1.154250	0.0000	Q1
0.921941	0.974188	1.154240	0.0000	O1
0.989049	0.998028	1.149150	0.0000	P1
0.999853	1.216397	1.134890	0.0000	K1
1.719381	1.906462	1.161720	0.0000	N2
1.923766	1.976926	1.161720	0.0000	M2
1.991787	2.002885	1.161720	0.0000	S2
2.003032	2.182843	1.161720	0.0000	K2
2.753244	3.081254	1.07338	0.0000	M3
3.791964	3.937897	1.03900	0.0000	M4

Ocean Load ON, Filename: G:\ABSOLU\DATA\INI\OceanLoad-Lake Village.olf

Waves: M2 S2 K1 O1 N2 P1 K2 Q1 Mf Mm Ssa
Amplitude (μGal): 0.727 0.297 1.038 0.620 0.094 0.317 0.070 0.124 0.000 0.000 0.000
Phase (deg): 88.4 22.7 50.8 63.4 111.0 51.5 11.7 72.8 0.0 0.0 0.0

Instrument Data

Meter Type: FG5
Meter S/N: 111
Factory Height: 116.33 cm
Rubidium Frequency: 10000000.00171 Hz
Laser: WEO100 (000000)
ID: 632.99117754 nm (0.48 V)
IE: 632.99119473 nm (-0.12 V)
IF: 632.99121259 nm (-0.50 V)
IG: 632.99123023 nm (-1.05 V)
IH: 632.99136890 nm (-1.45 V)
II: 632.99139822 nm (-1.20 V)
IJ: 632.99142704 nm (-0.90 V)
Modulation Frequency: 8333.420 Hz

Processing Results

Date: 08/29/09
Time: 04:04:37
DOY: 241
Year: 2009
Time Offset (D h:m:s): 0 0:0:0
Gravity: 979864511.58 μGal
Set Scatter: 1.22 μGal
Measurement Precision: 0.29 μGal
Total Uncertainty: 1.89 μGal
Number of Sets Collected: 31
Number of Sets Processed: 18
Set #s Processed: 2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19
Number of Sets NOT Processed: 13
Set #s NOT Processed: 1,20,21,22,23,24,25,26,27,28,29,30,31
Number of Drops/Set: 100
Total Drops Accepted: 1737
Total Drops Rejected: 63
Total Fringes Acquired: 700
Fringe Start: 12
Processed Fringes: 608
GuideCard Multiplex: 4
GuideCard Scale Factor: 250

Acquisition Settings
Set Interval: 30 min
Drop Interval: 10 sec
Number of Sets: 48
Number of Drops: 100

Gravity Corrections
Earth Tide (ETGTAB): -55.72 μGal
Ocean Load: -0.44 μGal
Polar Motion: -6.94 μGal
Barometric Pressure: 4.22 μGal
Transfer Height: 2.26 μGal
Reference Xo: -0.00 μGal

Uncertainties
Sigma Reject: 3.00
Earth Tide Factor: 0.001
Average Earth Tide Uncertainty: 0.06 μGal
Ocean Load Factor: 0.10
Average Ocean Load Uncertainty: 0.04 μGal
Barometric: 1.00 μGal
Polar Motion: 0.05 μGal
Laser: 0.05 μGal
Clock: 0.50 μGal
System Type: 1.10 μGal
Tidal Swell: 0.00 μGal
Water Table: 0.00 μGal
Unmodeled: 0.00 μGal
System Setup: 1.00 μGal
Gradient: 0.02 μGal (0.03 $\mu\text{Gal}/\text{cm}$)

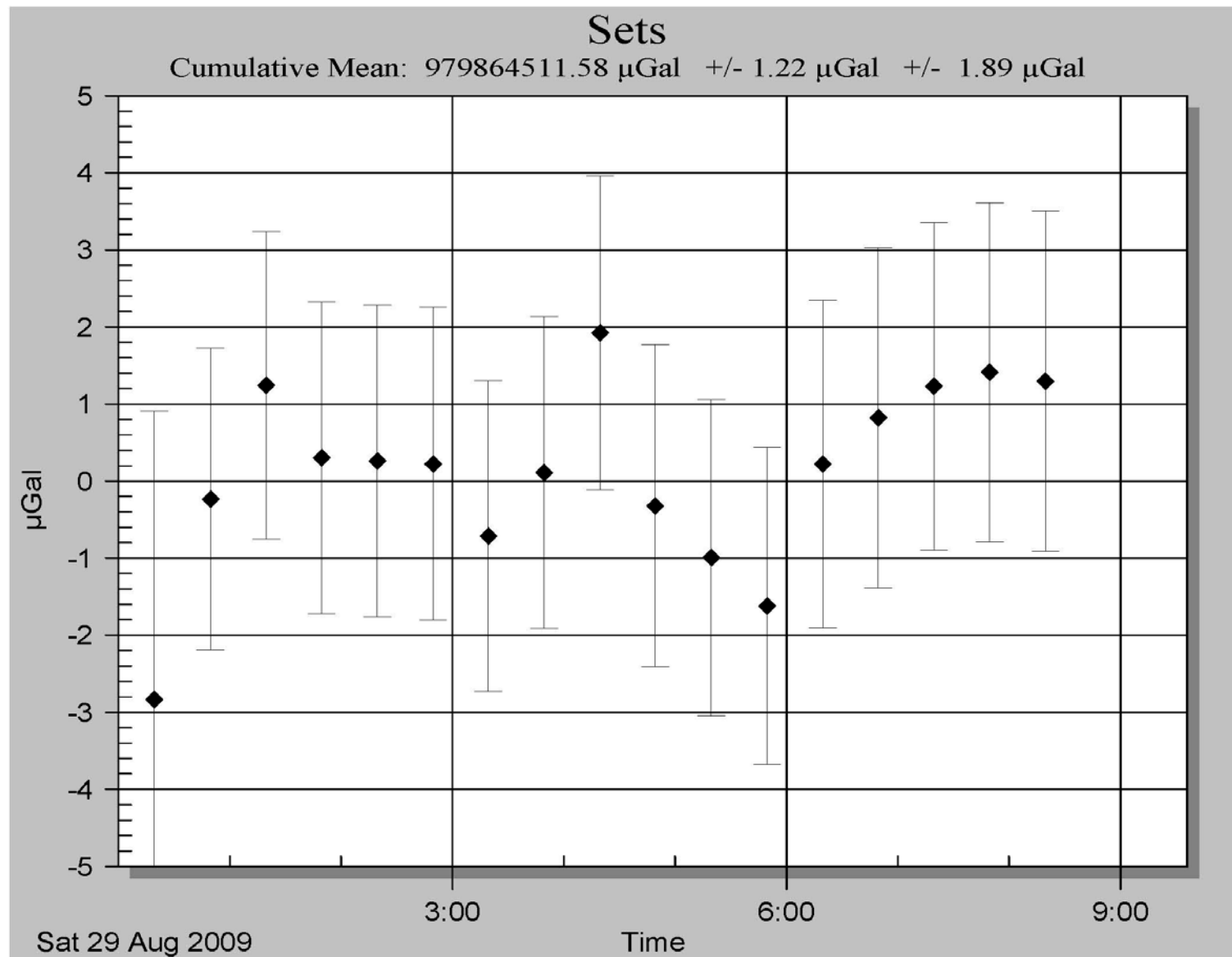
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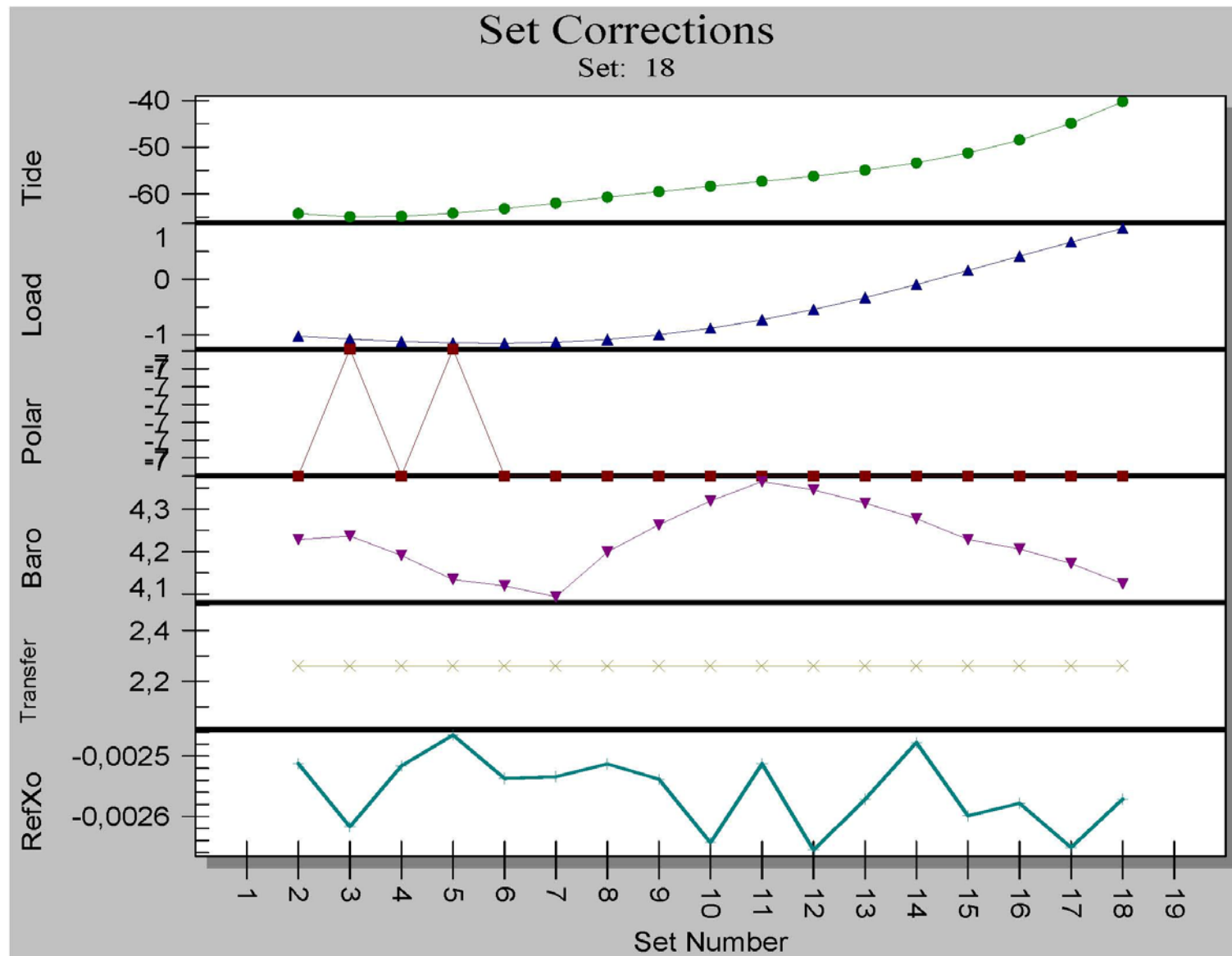
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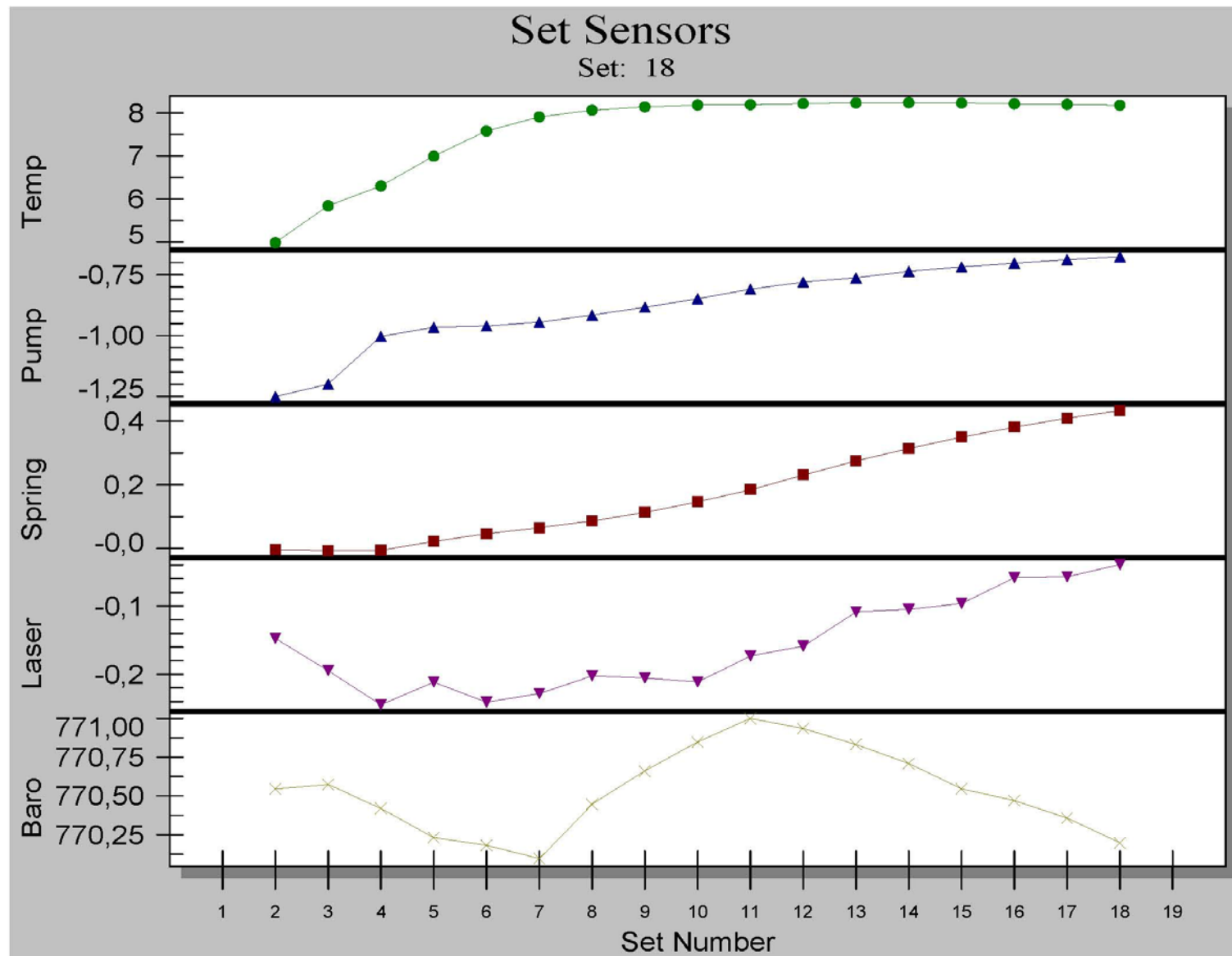
g Acquisition Version: 8.090111

g Processing Version: 7.070307

Set	Time	DOY	Year	Gravity	Sigma	Error	Uncert	Tide	Load	Baro	Polar	Transfer	Refxo	Temp	Pres	Accept	Reject
2	23:49:45	240	2009	979864508.370	8.038	0.825	2.040	-64.196	-1.022	4.229	-6.935	2.261	-0.003	4.980	770.545	95	5
3	00:19:18	241	2009	979864508.743	31.265	3.242	3.741	-64.876	-1.074	4.237	-6.935	2.261	-0.003	5.840	770.573	93	7
4	00:49:45	241	2009	979864511.344	5.846	0.600	1.960	-64.792	-1.117	4.191	-6.935	2.261	-0.003	6.296	770.421	95	5
5	01:19:43	241	2009	979864512.820	6.877	0.713	1.998	-64.144	-1.145	4.135	-6.935	2.261	-0.002	6.994	770.232	93	7
6	01:49:36	241	2009	979864511.880	7.574	0.777	2.022	-63.143	-1.151	4.120	-6.935	2.261	-0.003	7.580	770.183	95	5
7	02:19:38	241	2009	979864511.838	7.737	0.782	2.023	-61.953	-1.131	4.094	-6.935	2.261	-0.003	7.907	770.097	98	2
8	02:49:38	241	2009	979864511.799	8.034	0.803	2.031	-60.718	-1.081	4.199	-6.935	2.261	-0.003	8.064	770.447	100	0
9	03:19:27	241	2009	979864510.864	7.455	0.757	2.013	-59.529	-0.998	4.263	-6.935	2.261	-0.003	8.144	770.661	97	3
10	03:49:32	241	2009	979864511.687	7.727	0.785	2.023	-58.401	-0.880	4.319	-6.935	2.261	-0.003	8.187	770.847	97	3
11	04:19:39	241	2009	979864513.500	7.976	0.818	2.036	-57.319	-0.727	4.365	-6.935	2.261	-0.003	8.197	771.000	95	5
12	04:49:22	241	2009	979864511.254	9.319	0.951	2.092	-56.219	-0.544	4.345	-6.935	2.261	-0.003	8.218	770.935	96	4
13	05:19:36	241	2009	979864510.585	8.466	0.864	2.053	-54.942	-0.330	4.314	-6.935	2.261	-0.003	8.236	770.831	96	4
14	05:49:39	241	2009	979864509.956	8.673	0.872	2.056	-53.354	-0.095	4.278	-6.935	2.261	-0.002	8.238	770.709	99	1
15	06:19:47	241	2009	979864511.798	9.937	1.019	2.123	-51.260	0.156	4.229	-6.935	2.261	-0.003	8.232	770.546	95	5
16	06:49:38	241	2009	979864512.398	11.685	1.186	2.208	-48.504	0.412	4.206	-6.935	2.261	-0.003	8.215	770.471	97	3
17	07:19:37	241	2009	979864512.807	10.159	1.026	2.127	-44.881	0.668	4.172	-6.935	2.261	-0.003	8.198	770.358	98	2
18	07:49:38	241	2009	979864512.990	11.649	1.171	2.201	-40.242	0.913	4.124	-6.935	2.261	-0.003	8.181	770.197	99	1
19	08:19:42	241	2009	979864512.871	11.754	1.181	2.208	-34.479	1.140	4.067	-6.935	2.261	-0.003	8.164	770.008	99	1







STATION: OLD FAITHFUL - YELLOWSTONE			
City:	Old Faithful	Country:	USA
Location:	Yellowstone	Particularity:	
Situation:	Service area	Remarks:	
Date:	29-30 August 2009		
Code number:			
Latitude:	44.4564 degrees		
Longitude:	-110.8428 degrees		
Elevation:	2232 m		
Gradient:	-2.858 µgal/cm		
Reference height: 0. 1360 m + 1.1633 m = 1.2993 m			
Meter:	FG5		
S/N:	111		
Tidal corrections using observed tidal parameters			
Polar motion correction			Air pressure correction
X-coordinate	0.2688	arc seconds	Nominal air pressure: 772.32 mbar
Y-coordinate	0.4236	arc seconds	Barometric admittance factor: 0.3 µgal/mbar
Gravity			
Set gravity mean:	979 896 966.61	Microgal	
Set std. dev.:	0.98	microgal	
Number of sets:	50		
Number of drops per set:	100		
Drop interval:	10 seconds		
Set interval:	30 minutes		
Nominal/datum height:	1.30 m		
Author: O. Francis	University of Luxembourg		
Date: October 30, 2009			

Project file

Micro-g Solutions g Processing Report
File Created: 07/13/10, 15:29:00

Project Name: OF2009
g Acquisition Version: 8.090111
g Processing Version: 7.070307

Company/Institution: University of Luxembourg
Operator: Olivier Francis and David Schmerge

Station Data

Name: Old Faith
Site Code: Yellowstone
Lat: 44.45640 Long: -110.84280 Elev: 2232.00 m
Setup Height: 13.60 cm
Transfer Height: 130.00 cm
Actual Height: 129.93 cm
Gradient: -2.858 $\mu\text{Gal}/\text{cm}$
Nominal Air Pressure: 772.32 mBar
Barometric Admittance Factor: 0.30
Polar Motion Coord: 0.2688 " 0.4236 "
Earth Tide (ETGTAB) Selected
Potential Filename: C:\Program Files\Micro-g Solutions Inc\gWavefiles\ETCPOT.dat
Delta Factor Filename: G:\ABSOLU\DATA\INI\OceanLoad-Faith-Faith.dff
Delta Factors

Start	Stop	Amplitude	Phase	Term
0.000000	0.002427	1.000000	0.0000	DC
0.002428	0.249951	1.160000	0.0000	Long
0.721500	0.906315	1.154250	0.0000	Q1
0.921941	0.974188	1.154240	0.0000	O1
0.989049	0.998028	1.149150	0.0000	P1
0.999853	1.216397	1.134890	0.0000	K1
1.719381	1.906462	1.161720	0.0000	N2
1.923766	1.976926	1.161720	0.0000	M2
1.991787	2.002885	1.161720	0.0000	S2
2.003032	2.182843	1.161720	0.0000	K2
2.753244	3.081254	1.07338	0.0000	M3
3.791964	3.937897	1.03900	0.0000	M4

Ocean Load ON, Filename: G:\ABSOLU\DATA\INI\OceanLoad-Faith-Faith.olf
Waves: M2 S2 K1 O1 N2 P1 K2 Q1 Mf Mm Ssa
Amplitude (μGal): 1.002 0.326 1.570 0.942 0.137 0.484 0.062 0.183 0.000 0.000 0.000
Phase (deg): 137.7 61.8 55.7 69.0 176.4 56.3 53.5 78.5 0.0 0.0 0.0

Instrument Data

Meter Type: FG5
Meter S/N: 111
Factory Height: 116.33 cm
Rubidium Frequency: 10000000.00000 Hz
Laser: WEO100 (000000)
ID: 632.99117754 nm (0.48 V)
IE: 632.99119473 nm (0.00 V)
IF: 632.99121259 nm (-0.38 V)
IG: 632.99123023 nm (-1.05 V)
IH: 632.99136890 nm (-1.45 V)
II: 632.99139822 nm (-1.20 V)
IJ: 632.99142704 nm (-0.90 V)
Modulation Frequency: 8333.420 Hz

Processing Results

Date: 08/30/09
Time: 04:13:33
DOY: 242
Year: 2009
Time Offset (D h:m:s): 0 0:0:0
Gravity: 979896966.61 μ Gal
Set Scatter: 0.98 μ Gal
Measurement Precision: 0.19 μ Gal
Total Uncertainty: 1.88 μ Gal
Number of Sets Collected: 50
Number of Sets Processed: 26
Set #s Processed: 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,45,46,47,48,49,50
Number of Sets NOT Processed: 24
Set #s NOT Processed: 21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44
Number of Drops/Set: 100
Total Drops Accepted: 2404
Total Drops Rejected: 196
Total Fringes Acquired: 700
Fringe Start: 12
Processed Fringes: 608
GuideCard Multiplex: 4
GuideCard Scale Factor: 250

Acquisition Settings
Set Interval: 10 min
Drop Interval: 5 sec
Number of Sets: 50
Number of Drops: 100

Gravity Corrections
Earth Tide (ETGTAB): -32.84 μ Gal
Ocean Load: -1.40 μ Gal
Polar Motion: -5.75 μ Gal
Barometric Pressure: 2.44 μ Gal
Transfer Height: -0.20 μ Gal
Reference Xo: -0.00 μ Gal

Uncertainties
Sigma Reject: 3.00
Earth Tide Factor: 0.001
Average Earth Tide Uncertainty: 0.03 μ Gal
Ocean Load Factor: 0.10
Average Ocean Load Uncertainty: 0.14 μ Gal
Barometric: 1.00 μ Gal
Polar Motion: 0.05 μ Gal
Laser: 0.05 μ Gal
Clock: 0.50 μ Gal
System Type: 1.10 μ Gal
Tidal Swell: 0.00 μ Gal
Water Table: 0.00 μ Gal
Unmodeled: 0.00 μ Gal
System Setup: 1.00 μ Gal
Gradient: -0.00 μ Gal (0.03 μ Gal/cm)

Set File

Source Data Filename: OF2009

g Acquisition Version: 8.090111

g Processing Version: 7.070307

Set	Time	DOY	Year	Gravity	Sigma	Error	Uncert	Tide	Load	Baro	Polar	Transfer	Refxo	Temp	Pres	Accept	Reject
1	22:16:15	241	2009	979896965.039	13.204	1.384	2.324	-44.888	-1.279	2.628	-5.745	-0.200	-0.003	7.891	781.081	91	9
2	22:26:11	241	2009	979896968.747	10.173	1.061	2.147	-47.998	-1.314	2.611	-5.745	-0.200	-0.002	8.078	781.025	92	8
3	22:36:10	241	2009	979896965.753	11.570	1.175	2.206	-50.919	-1.350	2.618	-5.745	-0.200	-0.002	8.213	781.047	97	3
4	22:46:10	241	2009	979896966.185	10.646	1.081	2.158	-53.621	-1.386	2.605	-5.745	-0.200	-0.002	8.318	781.002	97	3
5	22:56:02	241	2009	979896966.893	11.370	1.179	2.209	-56.074	-1.423	2.595	-5.745	-0.200	-0.002	8.405	780.969	93	7
6	23:06:12	241	2009	979896966.252	10.260	1.064	2.150	-58.364	-1.461	2.631	-5.745	-0.200	-0.002	8.488	781.091	93	7
7	23:16:07	241	2009	979896967.757	15.421	1.582	2.448	-60.372	-1.498	2.644	-5.745	-0.200	-0.002	8.549	781.134	95	5
8	23:26:04	241	2009	979896968.036	12.047	1.307	2.280	-62.161	-1.535	2.659	-5.745	-0.200	-0.002	8.589	781.182	85	15
9	23:36:06	241	2009	979896967.478	10.355	1.068	2.153	-63.735	-1.573	2.665	-5.745	-0.200	-0.002	8.618	781.203	94	6
10	23:46:08	241	2009	979896965.654	9.782	1.014	2.127	-65.081	-1.610	2.658	-5.745	-0.200	-0.002	8.642	781.179	93	7
11	23:56:00	241	2009	979896965.318	8.041	0.834	2.047	-66.186	-1.646	2.624	-5.745	-0.200	-0.002	8.670	781.067	93	7
12	00:06:07	242	2009	979896965.226	11.321	1.138	2.189	-67.098	-1.682	2.611	-5.745	-0.200	-0.002	8.700	781.022	99	1
13	00:16:14	242	2009	979896964.865	14.327	1.519	2.409	-67.795	-1.716	2.607	-5.745	-0.200	-0.002	8.715	781.009	89	11
14	00:26:03	242	2009	979896965.201	13.413	1.422	2.350	-68.273	-1.748	2.613	-5.745	-0.200	-0.002	8.721	781.031	89	11
15	00:36:06	242	2009	979896965.587	12.892	1.337	2.300	-68.568	-1.780	2.611	-5.745	-0.200	-0.002	8.723	781.024	93	7
16	00:46:18	242	2009	979896966.109	9.912	1.045	2.143	-68.677	-1.809	2.616	-5.745	-0.200	-0.002	8.723	781.039	90	10
17	00:56:07	242	2009	979896966.355	10.798	1.126	2.184	-68.610	-1.835	2.620	-5.745	-0.200	-0.002	8.726	781.053	92	8
18	01:06:11	242	2009	979896966.899	13.610	1.404	2.340	-68.380	-1.859	2.609	-5.745	-0.200	-0.002	8.730	781.018	94	6
19	01:16:13	242	2009	979896966.120	17.961	1.853	2.634	-68.001	-1.880	2.602	-5.745	-0.200	-0.002	8.724	780.995	94	6
20	01:26:07	242	2009	979896966.213	12.406	1.273	2.264	-67.491	-1.897	2.603	-5.745	-0.200	-0.002	8.711	780.998	95	5
45	18:25:25	242	2009	979896966.636	15.938	1.816	2.602	73.485	-0.569	1.902	-5.745	-0.200	-0.002	9.504	778.660	77	23
46	18:33:25	242	2009	979896968.203	8.803	0.918	2.078	70.714	-0.616	1.869	-5.745	-0.200	-0.002	9.493	778.548	92	8
47	18:42:43	242	2009	979896967.312	6.846	0.714	1.996	67.270	-0.669	1.852	-5.745	-0.200	-0.002	9.483	778.493	92	8
48	18:52:39	242	2009	979896966.793	8.235	0.849	2.048	63.337	-0.721	1.832	-5.745	-0.200	-0.002	9.469	778.426	94	6
49	19:02:46	242	2009	979896967.416	7.392	0.754	2.011	59.077	-0.772	1.802	-5.745	-0.200	-0.002	9.460	778.326	96	4
50	19:12:42	242	2009	979896966.543	7.011	0.719	1.998	54.663	-0.818	1.791	-5.745	-0.200	-0.002	9.458	778.288	95	5

